

Effects of Mineral-Nutrient Deficiencies and Excesses upon the Vegetative Growth and Flowering of Sweet Peas

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EXPERIMENTAL PLOTS OF SWEET PEAS IN SHALLOW SOIL

Published by the
Cornell University Agricultural Experiment Station
Ithaca, New York

Received for publication June 25, 1940



EFFECTS OF MINERAL-NUTRIENT DEFICIENCIES AND EXCESSES UPON THE VEGETATIVE GROWTH AND FLOWERING OF SWEET PEAS

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Hardening of plants in their early stages of growth and dropping of the flower buds are important problems to growers of sweet peas. The hardened plants are somewhat unusual in that they have dark green, small leaves and short internodal spaces. The dropping of flower buds occurs mostly during the winter months, although it has been observed during summer in outdoor plantings. The buds drop in various stages of development.

Allen (1925), Ball (1930), Brett, Cuthbertson (1915), Dick (1914), Lambert (1927), Laurie and Poesch (1939), Stevenson (1910), Sydenham (1910), Taubenhau (1917), Unwin (1929), and Wright (1910) recommend a well-fertilized soil and additional fertilizer applications during the growing period of sweet peas to overcome hardening. Bud drop is generally considered to be associated with excess nitrogen fertilizer.

Unpublished work by the author (1928) showed hardening of plants to be correlated with high nitrogen content of the soil. Additions of organic materials to a soil high in nitrate increased the succulency of growth and increased the bud drop of the plants. Similar results were reported by Laurie and Link (1934). Farnham (1935) reported that high concentrations of a complete nutrient solution applied to plants in gravel culture resulted in less bud drop and shorter stems than did lower concentrations. These experiments are considered in three parts:

1. Reducing and increasing the level of nitrate in soil cultures.
2. Nutrient deficiencies and excesses in sand cultures treated with nutrient solutions.
3. Extreme excesses of nitrogen, phosphorus, and potash in soil cultures, and means of correcting these excesses.

These investigations were carried on in the Cornell University greenhouses during the period 1931 to 1939. The purpose was to determine the effects of high and low nutrient levels, in soil and gravel culture, on the hardening of vines and dropping of buds during the winter and spring.

MATERIALS AND METHODS

The plants in the first series of experiments were grown in soils of different levels of nitrate concentration. Soils high in nitrate were treated with chopped straw (one-fifth by volume) or granulated sugar to reduce the nitrate concentration. Soils low in nitrate were treated with nitrate of soda when it was desired to increase the nitrate concentration. In either case results on the original soil were compared with those from the treated soil.

Some of the experiments were conducted in the greenhouse raised bench in five inches of soil and other experiments were conducted in ground beds where the treated soil was twelve inches deep and the plants could root into the clay subsoil. A few of the later experiments were

conducted in six-gallon galvanized cans with a two-inch hole in the bottom for drainage.

Sand-culture experiments were made to study deficiencies of nitrogen, phosphorus, and potassium and to study various concentrations of the fertilizer elements. The sand particles were $\frac{1}{16}$ to $\frac{1}{4}$ inch in diameter. These experiments were conducted in the six-gallon galvanized containers. Three liters of nutrient solution was poured on the sand once each week, unless otherwise stated. This was sufficient to thoroughly saturate the sand. The sand was flushed with nine liters of tap water two days before the nutrient solution was applied. The nutrients used are discussed under each experiment. Baker's analyzed chemicals were used in the sand cultures, and commercial fertilizers in the soil cultures. The sand was moistened with tap water between nutrient applications if it appeared to require water.

Plants in soil were watered when the soil appeared somewhat dry. All plots were watered at the same rate. The greenhouse temperature was maintained at 50° F. at night when outside temperatures permitted, otherwise it was reduced as much as possible. The daytime temperature was 5 to 10 degrees above the night temperature.

Fully opened flowers were picked every second day. They were graded by length of stem, less than 3 inches, 3 to 6 inches, 6 to 9 inches, 9 to 12, etc. The average length for the group was used in calculating stem length. The average for the 3-to-6-inch grade was 4.5.

The variety Zvolanek's Rose was used in the first two treatments, Ball's Rose in the third, and Majestic Rose in all other treatments except where specified.

Nitrate-nitrogen determinations were made by the phenol-di-sulfonic acid method, using 100 grams of air-dry soil. Determinations of pH were made by the quinhydrone electrode. High pH readings were generally obtained with high organic content of the soil.

SOIL CULTURES

The first series of experiments was conducted in the greenhouse bench in five inches of composted soil and in composted soil treated with chopped oat straw. Twenty plants were placed across a three-foot bench. Five three-foot rows, placed two and one-half feet apart, were used in each treatment. Seeds were planted March 10, 1931. The production period extended from May 29 to June 10. The results (table 1) show that the production of flowers was greater and the stem length greater in the soil which was treated with straw. The plants in the untreated composted soil showed typical hardened growth.

TABLE 1. PRODUCTION OF STRAW-TREATED AND OF COMPOSTED SOIL

	Average flowers per row (number)	Average stem length (inches)
Composted soil.....	66.6	6.7
Composted soil plus straw.....	77.9	9.2

Tests showed that untreated soil was extremely high in nitrate (table 2) during the growing period.



FIGURE 1. EFFECTS OF CHOPPED STRAW IN SOILS HIGH IN NITROGEN
Left, soil and straw added
Right, soil

TABLE 2. RESULTS OF NITRATE TESTS

	Date					
	March 25	April 8	April 22	May 6	May 20	June 3
	Parts per million					
Compost.....	466	410	466	800	160	640
Compost and straw.....	155	41	127	133	66	23

HIGH NITRATE AT VARIOUS STAGES OF GROWTH

Some recommendations are to add fertilizer at the time flowering starts to prevent hardening and to stimulate production and stem length. A test was made in ground beds to determine the effects of applications of nitrate of soda at the beginning of growth, before flowering, and after the first flowers were picked.

The seeds were planted directly in the greenhouse bed on November 24, in 36-inch rows. The treatments were made in triplicate, and the data given in table 3 represent the averages for the three treatments. Nitrate of soda at the rate of 1 pound per 100 linear feet of row was added to one plot each month until the plants began to flower, when no further treatment was given. Another plot was treated with nitrate of soda, at the same rate, when the first flowers were cut, and once each week during the flowering period. The third plot was treated with straw, and the nitrate added each month until flowering began. The fourth plot was grown in composted soil given no treatment. The fifth was treated with straw and not fertilized, and the sixth treated with one-fifth (by volume) of cow manure.

The results (table 3) show that nitrate applications at the beginning of growth delayed production. The additions of straw and manure produced longer stems on the first flowers and continued to give longer stems during the entire production period. The nitrate application to straw-treated soil caused the development of shorter stems on the earliest flowers but of longer stems during the last two weeks of production. Nitrate application to soil gave results similar to those from straw-treated soils fertilized with nitrate. Nitrate application at the time flowering began gave shorter stems but increased the production slightly.

No visible symptoms of hardening or injury to the plants appeared in the treatments.

Nitrate tests were made on the various plots on May 6 and June 3. The results appear in table 4.

Stem length was inversely related to the nitrate concentration in the soil.

SOIL AND NITRATE VARIATIONS

On August 12, 1932, composted soil and Dunkirk silty clay loam field soil were placed in the greenhouse bench in different plots. Each plot was treated with 20-per-cent superphosphate at the rate of 5 pounds per 100 square feet of bench area, except where noted. Seeds of the variety Ball's Rose Improved were planted on August 15. Two rows were

TABLE 3. EFFECTS OF NITRATE UPON PRODUCTION AND STEM LENGTH

Plot		Week ending—										
		April 1	April 8	April 15	April 23	April 30	May 7	May 13	May 20	May 27	June 4	Total
Nitrate at beginning	Number of flowers* Stem length†	3.3 8.20	17.0 8.97	27.3 9.27	73.0 9.53	61.7 9.57	78.0 9.74	79.3 9.39	194.3 9.29	188.0 7.82	382.3 8.18	1,104.2 8.72
Nitrate at bloom	Number of flowers* Stem length†	26.0 8.62	51.0 9.56	61.3 9.72	86.7 9.94	63.0 8.99	111.0 9.02	115.0 8.81	193.7 8.59	212.3 6.84	357.7 6.34	1,277.7 7.93
Straw plus nitrate	Number of flowers* Stem length†	1.7 9.70	14.0 10.29	26.3 11.37	47.3 11.66	42.0 11.21	69.0 11.39	70.0 11.40	150.7 11.05	173.7 8.77	320.3 8.09	915.0 9.67
No treatment	Number of flowers* Stem length†	19.7 9.72	57.0 10.07	52.0 10.19	79.0 10.86	58.7 10.27	95.3 10.05	96.3 9.99	154.7 9.31	195.3 7.64	320.3 6.99	1,128.3 8.72
Straw	Number of flowers* Stem length†	20.7 10.91	50.7 11.81	51.0 12.62	77.0 13.22	49.0 11.83	100.7 11.66	96.3 11.04	166.3 10.33	208.3 8.46	358.3 7.67	1,178.3 9.78
Manure	Number of flowers* Stem length†	27.3 10.47	41.3 10.96	43.0 11.66	71.0 12.37	52.7 11.50	89.3 10.84	86.3 10.65	137.3 9.99	201.0 8.18	292.7 7.36	1,041.9 9.39

*Number per 36-inch row.

†Average length in inches.

TABLE 4. RESULTS OF NITRATE-NITROGEN TESTS

Treatment	Parts per million	
	May 6	June 3
	Parts per million	
Nitrate at beginning.....	145	40
Nitrate at bloom.....	400	114
Straw plus nitrate.....	72	23
No treatment.....	160	48
Straw.....	20	19
Manure.....	38	38

planted two and one-half feet apart in each 3-by-5-foot plot, and the plants were thinned to 20 in each 3-foot row. The straw and the rotted manure were used at the rate of $\frac{1}{5}$ by volume of the total mixture. The sodium nitrate was used at the rate of 1 pound per 100 square feet of bench area. It was applied at two-week intervals after the soil sample which was to be tested for nitrates had been removed. Granulated sugar was applied at the rate of 5 pounds per 100 square feet of bench area at two-week intervals.

Three of the extra plants which had been growing between the rows were removed for nodulation studies, 6 and 12 weeks after the seed had been sown. The heights of the plants were also recorded at these times. The data are given in table 5.

TABLE 5. SOIL AND COMPOST CULTURES

Treatment	Average height (inches)		Average number nodules per plant	
	Sept. 17	Oct. 30	Sept. 17	Oct. 30
Compost.....	10.0	42.6	0.3	10.0
Compost and straw.....	8.0	35.5	15.0	8.5
Compost and NaNO_3	9.0	37.3	1.3	3.3
Compost and sugar.....	10.0	26.3	5.6	10.2
Compost and straw, no phosphate.....	6.3	39.0	11.0	15.0
Soil.....	12.3	39.6	7.0	4.0
Soil and manure.....	5.3	32.6	12.3	33.0
Soil and straw.....	10.7	35.0	6.6	11.6
Soil and straw, no phosphate	7.3	37.0	23.3	32.6

The plants in untreated soil and compost grew most rapidly at first. The straw and rotted manure delayed growth through the first six weeks, and the leaves of the plants became yellow-green in color. During the second six-weeks period, growth was similar to that of the first. The foliage continued to be a yellow-green color where the soil was treated with straw.

The number of nodules was greatest at the end of the first six weeks in the straw-treated soils. These continued to grow and were much larger than those on the plants from untreated soil after twelve weeks. The number of nodules increased in composted soil and in other treatments, except in compost treated with straw and in the untreated soil. Here the error in sampling is doubtless responsible for the reduction in number of nodules. Variability is great between plants, and not enough were treated to establish the significance of the treatment.

In table 6 it is shown that length of stem was slightly greater when straw was incorporated into the soil. The number of buds which dropped was not affected by the treatment, when considered in light of the number of stems produced.

TABLE 6. AVERAGE OF TOTAL PRODUCTION, STEM LENGTH, AND BUD DROP PER ROW

Treatment	Number of stems	Stem length (inches)	Buds dropped
Compost	995.5	8.8	433.0
Compost and straw	984.5	9.2	412.0
Compost and NaNO_3	1,049.0	9.2	444.5
Compost and sugar	964.5	9.2	460.5
Compost and straw, no phosphate	943.0	9.3	450.5
Soil	1,064.0	9.2	352.0
Soil and straw	784.6	9.4	240.0
Soil and manure	966.5	9.3	388.5
Soil and straw, no phosphate	852.6	9.4	359.0

In table 7 it is shown that the nitrate concentration was reduced greatly by the addition of straw. The nitrate application to straw-treated soil was effective in maintaining a high level of nitrate. Sugar reduced the nitrate but did not keep it at a low level more than a short time. The extremely high nitrate concentration was apparently neither beneficial nor detrimental to the plants during this treatment. At the time the flowers were ready to pick the nitrate levels were about the same in all plots.

TABLE 7. NITRATES IN COMPOST AND SOIL TREATMENTS

	Date of sampling						
	Aug. 15	Sept. 12	Oct. 10	Nov. 7	Dec. 5	Jan. 2	Jan. 30
	Parts per million						
Compost	467	600	266	88	47	30	27
Compost and straw	280	24	22	20	29	27	22
Compost and NaNO_3	467	600	267	350	78	40	109
Compost and sugar	93	200	0	40	0	17	trace
Compost and straw, no phosphate	467	20	23	40	30	19	17
Soil	156	120	100	88	9	20	15
Soil and straw	74	0	0	23	11	13	10
Soil and manure	233	200	114	140	35	22	20
Soil and straw, no phosphate	116	10	0	23	28	14	14

TESTS WITH SANDY SOIL TREATED WITH NITRATE

On August 14, 1933, sandy loam soil which had been composted with one-fourth by volume of manure, was placed in the bench. The soil was sterilized with steam for thirty minutes at a temperature of 160° F. and was leached with tap water after sterilization. Sixteen-per-cent super-phosphate was added at the rate of five pounds per 100 square feet of bench area. Two boards, which were separated by a one-inch air space, divided the three-foot bench into plots five feet long. Straw and nitrate of soda were used at the same rate as in previous tests. One row of

seeds of the variety Majestic Rose, and a second row, two and one-half feet from the first, of Harmony were planted directly in the soil after the straw and phosphate had been incorporated. The plants were thinned to twenty per three-foot row. The treatments were in duplicate. The treatment, total production, stem length, and bud drop per row are given in table 8. The nitrate tests and pH determinations were made before fertilization and at intervals of two weeks thereafter. The results appear in table 9.

The straw treatment increased production of both varieties. It also increased the bud drop and produced longer stems. Bimonthly applications of nitrogen to straw-treated soils gave erratic results, but the tendency was to increase production, reduce the bud drop, and reduce the stem length. Weekly applications of nitrogen reduced production, stem length, and bud drop.

TABLE 8. AVERAGE PRODUCTION, BUD DROP, AND STEM LENGTH OF TREATED SANDY SOIL PER THREE-FOOT ROW
(Production period, December 1 to February 26)

Treatment	Variety	Number of stems	Stems with no flowers	Buds absent on stems with flowers	Stem length (inches)
Soil and straw	Majestic Rose	527	90	464	8.3
	Harmony	389	102	426	7.7
Soil, straw, and N bimonthly	Majestic Rose	377	25	248	6.0
	Harmony	420	14	181	6.2
Soil, straw, and N weekly	Majestic Rose	240	3	81	5.1
	Harmony	248	2	101	5.7
Soil	Majestic Rose	350	26	187	8.0
	Harmony	332	42	168	7.4
Soil and N bimonthly	Majestic Rose	359	8	145	6.0
	Harmony	401	18	166	5.9
Soil and N weekly	Majestic Rose	190	4	86	5.1
	Harmony	315	8	119	5.6

The incorporation of straw into the soil reduced the nitrate concentration, and the application of nitrate counteracted this effect. The medium level of nitrate resulted in an increase of production in comparison with the low or high nitrate concentration of the soil. High nitrate content of the soil resulted in fewer flowers than did low or medium nitrate. The higher nitrate content of the soil gave shorter stems and less bud drop.

NUTRIENT DEFICIENCY AND EXCESS IN SAND CULTURES

The following experiments were made in sand cultures to determine the appearance of the plants when either nitrogen, phosphorus, or potassium was lacking or in excess.

The variety Harmony was used in all treatments. Seeds were planted in sand, and five seedlings were transferred to each can on November 3, 1934, when the secondary roots were visible.

The fertilization treatment was started on November 12. There were five replications of the treatments, which were arranged in the greenhouse to compensate for temperature and light variations.

TABLE 9. NITRATE NITROGEN AND pH OF SANDY SOIL

Date	Plot											
	Straw		Straw and NO ₃ bimonthly		Straw and NO ₃ weekly		Straw and sugar		No treatment		NO ₃ bimonthly	
	N	pH	N	pH	N	pH	N	pH	N	pH	N	pH
August 8*	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
August 14†	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
August 23	4	.....	4	.....	4	.....	1.8	.....	1.8	.....	1.8	.....
September 6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
September 23	17	.....	33	.....	33	.....	2.7	.....	2.7	.....	2.7	.....
October 7	28	7.4	125	6.6	333	6.2	40	7.3	67	6.7	143	6.4
October 14	13	7.9	143	7.0	333	6.7	6	7.8	50	7.0	111	6.4
October 28	7	7.2	333	6.4	500	6.1	9	7.3	45	7.0	182	5.8
November 4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
November 11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
November 18	9	7.2	266	6.4	571	6.6	8	7.6	25	7.2	308	6.0
November 25	12	7.6	545	6.9	600	7.0	6	8.0	13	7.5	400	6.6
December 5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
December 16	20	7.6	333	7.1	500	6.9	5	7.6	17	7.0	286	6.8
December 24	5	7.4	200	6.8	133	7.1	3	7.8	9	7.2	320	7.0
January 6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
January 22	8	7.3	100	6.9	160	7.0	0	7.6	6	7.1	222	6.7
February 3	13	7.3	71	6.8	100	7.1	8	7.4	14	7.1	60	6.8
.....	10	7.3	57	6.4	50	7.4	6	7.4	10	7.5	33	7.1

*Sampled before sterilizing, all plots 125 parts per million, pH 6.8.

†Sampled after sterilizing but before leaching, all plots 133 parts per million; leached with cold water after sampling.

Modified Knop's solution made of Baker's analyzed chemicals was used.

- | | |
|--|------------------------------|
| 1. $\text{MgSO}_4 - 7 \text{H}_2\text{O}$ | 5. KCl |
| 2. $\text{Ca}(\text{NO}_3)_2 - 4 \text{H}_2\text{O}$ | 6. CaCl_2 |
| 3. KNO_3 | 7. NaNO_3 |
| 4. KH_2PO_4 | 8. NaH_2PO_4 |

Stock solutions were prepared by dissolving all salts in distilled water at the rate of 30 grams per liter. The solution applied to the sand was built up to 3 liters with tap water. The treatments are listed below. The results are given in table 10.

The solutions used were as follows:

- A. Complete solution, 25 c.c. of 1, 2, 3, 4.
- B. Minus nitrogen, 25 c.c. of 1 and 4; 18.4 c.c. of 5; 16.9 c.c. of 6.
- C. Low nitrogen, 25 c.c. of 1 and 4; 18.4 c.c. of 5; 16.9 c.c. of 6; 1.5 c.c. of 7.
- D. High nitrogen, 25 c.c. of 1, 2, 3, 4, and 776.4 c.c. of 7.
- E. No potash, 25 c.c. of 1 and 2; 13.2 c.c. of 7; 20.7 c.c. of 8.
- F. High potash, 25 c.c. of 1, 2, 3, 4, and 543 c.c. of 5.
- G. No phosphate, 25 c.c. of 1, 2, 3, and 13.7 c.c. of 5.
- H. High phosphate, 25 c.c. of 1, 2, 3, 4, and 706.5 c.c. of 8.

SAND-CULTURE TREATMENTS

Key*	Treatment
A	Complete solution
A—bl—B	Complete solution until bloom, then minus nitrogen
A—6—B	Complete solution for 6 applications, then minus nitrogen
B	No nitrogen
B—6—A	No nitrogen for 6 applications, then complete solution
B—bl—A	No nitrogen until bloom, then complete solution
B—6—D	No nitrogen for 6 applications, then high nitrogen
B—bl—D	No nitrogen until bloom, then high nitrogen
D—6—B	High nitrogen for 6 applications, then minus nitrogen
D—bl—B	High nitrogen until bloom, then minus nitrogen
D	High nitrogen constantly
C	Low nitrogen constantly
F	High potassium
E	No potassium
H	High phosphate
G	No phosphate

*bl = bloom.

The average production, stem length, and bud drop of the five replications are given in table 10. pH determinations of the sand at the close of the experiment showed the lowest to be 6.5, and the highest 7.5. Extra plants were grown in each can for the purpose of studying root growth and nodulation.

RESPONSE TO NITROGEN

Highest production was obtained when the nutrient solution contained no nitrogen, a very small amount of nitrogen, or an extremely high concentration of nitrogen during the major portion of the early growing

TABLE 10. PRODUCTION OF SAND CULTURES

Treatment*	Stems with flowers (number)	Stem length (inches)	Stems with no buds (number)	Buds absent per stem with flowers
A.	24.4 ± 2.61	8.9 ± 0.15	23.0 ± 2.70	1.36 ± 0.11
A-bl-B.	43.4 ± 2.22	6.3 ± 0.12	11.8 ± 2.36	0.88 ± 0.06
A-6-B.	50.8 ± 2.87	5.9 ± 0.50	2.4 ± 0.66	0.48 ± 0.01
B.	64.2 ± 0.60	6.7 ± 0.09	4.0 ± 1.24	0.58 ± 0.03
B-bl-A.	53.8 ± 3.20	7.6 ± 0.17	11.0 ± 1.05	0.80 ± 0.07
B-6-A.	36.4 ± 2.58	9.1 ± 0.12	27.0 ± 1.43	1.32 ± 0.13
D.	51.8 ± 7.01	6.7 ± 0.72	2.6 ± 1.21	0.54 ± 0.27
D-bl-B.	34.2 ± 3.98	6.2 ± 0.45	2.0 ± 0.47	0.60 ± 0.63
D-6-B.	30.4 ± 4.65	7.4 ± 0.32	3.0 ± 1.81	0.62 ± 0.07
B-bl-D.	66.6 ± 5.05	6.0 ± 0.09	2.5 ± 0.90	0.52 ± 0.04
B-6-D.	48.0 ± 2.83	6.6 ± 0.45	3.8 ± 1.50	0.56 ± 0.05
C.	46.8 ± 1.91	5.8 ± 0.27	0.4 ± 0.04	0.40 ± 0.06
E.	43.6 ± 1.52	7.7 ± 0.17	9.6 ± 1.19	0.90 ± 0.03
F.	8.6 ± 1.79	5.1 ± 0.25	1.0 ± 0.47	0.84 ± 0.08
H.	14.6 ± 2.40	4.06 ± 0.13	0	0.62 ± 0.04
G.	No production			

*bl = bloom.

period. An intermediate amount of nitrogen, and high nitrogen at the beginning, followed by no nitrogen, resulted in the smallest number of flowers. Production and stem length were inversely related. The greatest length of stem was produced when an intermediate amount of nitrogen was present in the nutrient solution during the major portion of the early growing period. No nitrogen followed by high nitrogen or high nitrogen followed by no nitrogen caused the shortest stems.

Bud drop was greatest when the nitrogen content of the solution was intermediate, and least when the nitrogen content was high or low. Bud drop and high production were inversely related. Bud drop and long stems were directly related.

Nitrogen deficiency appeared in the leaves of plants as a uniform yellowing. Some of the leaves died but remained on the plant. Plants given no nitrogen in the nutrient solution showed yellowing in the leaves after 20 weeks, on April 1. Nitrogen added to the nutrient solution after the plants began flowering prevented the deficiency from showing in the leaves. Nitrogen removed from the solution after 6 weeks or at the time of flowering caused the leaves to become yellow-green within a few days.

Branching of the plants was less where nitrogen was lacking. The most vigorous growth occurred where nitrogen was intermediate in concentration. Nodulation was greatest and the nodules were largest where nitrogen was lacking or very low in concentration (table 11). Some root injury was evident in the high-nitrogen treatments. Excess nitrogen

TABLE 11. AVERAGE NODULATION AT THE END OF SIX WEEKS IN SAND

Treatment	Average number of nodules per plant	Size of nodules
A.	4.2	Small
B.	4.7	Large
C.	4.2	Large
D.	2.2	Small
E.	2.0	Small
G.	2.0	Small
H.	2.5	Small



FIGURE 2. LEAF DROP CAUSED BY LACK OF POTASSIUM

caused the leaves to become yellow-green between the veins and eventually to die and hang on the plant. Growth was dwarfed and hardened.

RESPONSE TO POTASSIUM

A nutrient solution deficient in potassium caused an intermediate amount of flowering, and an intermediate number of stems and amount of bud drop. The plants were extremely succulent, and on January 27 the lower leaves were dropping from them.

The leaf injury appeared as marginal necrosis. Before the entire leaf was necrotic it fell from the plant. The loss of leaves continued from the base to the top of the plant, until it was entirely defoliated. The plants reached a height of eight feet before this occurred. Root and terminal growth were normal and nodulation poor.

Excess potassium injured the terminal growing point and promoted basal branching. Root injury was similar to the excess-nitrogen treatment. The leaves became yellow-green but the veins remained green. Stems were short, production poor, and bud drop slight.

RESPONSE TO PHOSPHATE

A nutrient solution deficient in phosphorus produced very small leaves which were blue-green in color. The tendrils became deep bronze in color. The internodal spaces were very short, and very few flowers were produced. The leaves at the base of the plant died when small, and the stems were hard. These symptoms are much like the typical hardening symptoms which have been observed in some commercial greenhouses. The roots were white in color and normal for the size of the plant, but nodulation was very poor.

Excess phosphorus gave poor production, a medium number of stems, and little bud drop. The older leaves became necrotic from the margin inward. They dropped before completely dry. The veins were the last portion to show injury. The leaf injury was similar to that in the minus-potassium treatment. The roots became brown, and branched very little.

VARYING THE RATIO OF THE NUTRIENTS

A second series of sand-culture experiments were made to determine the effects of varying the ratio of nitrogen, phosphorus, potassium, and magnesium. No element was entirely lacking in any treatment, and it was planned that no element would be of sufficient concentration to cause immediate injury to the plants. Shive's R_2S_4 solution, as used by Farnham, was used in these experiments. The sand was of the same type, and the amount of solution was the same as used in the previous experiment.

The check solution had a concentration of $\frac{1}{2}$ atmosphere. The high-salt solution was four times this concentration. In those treatments where one element was high in the solution, it was added at the same rate as in the concentrated solution.

The stock solutions were made as follows:

1. KH_2PO_4 , 12.64 gm. per liter.
2. $Ca(NO_3)_2 \cdot 4H_2O$, 45.6 gm. per liter.

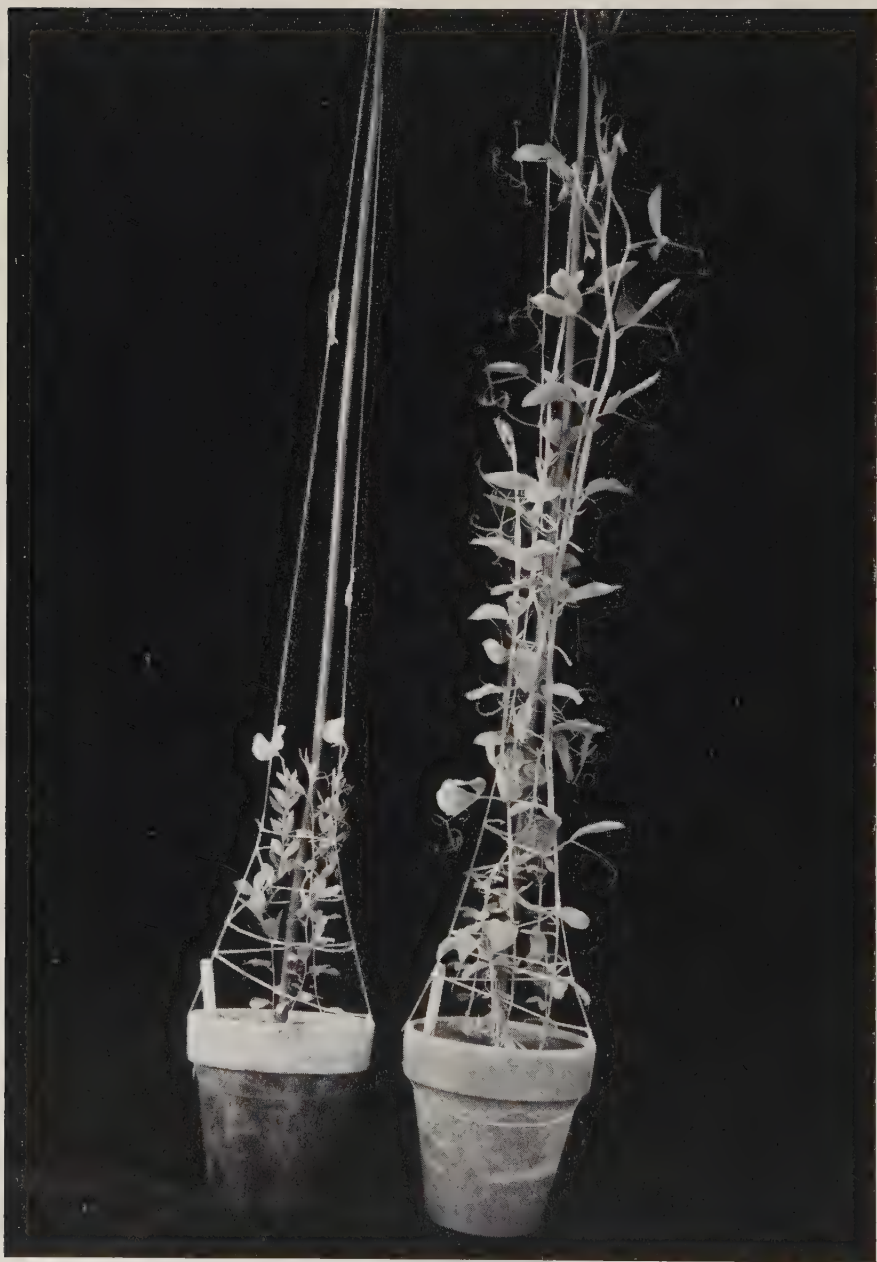


FIGURE 3. HARDENING CAUSED BY DEFICIENCY OF PHOSPHATE

Left, no phosphate
Right, phosphate added

3. $\text{MgSO}_4 \cdot 7 \text{H}_2\text{O}$, 24.2 gm. per liter.

4. KCl , 6.86 gm. per liter.

5. NaH_2PO_4 , 11.15 gm. per liter.

Tap water was used for all experiments. The stock solutions comprising each of the following treatments were made up to a liter:

one-half atmosphere, 25 c.c. of stock solutions 1, 2, and 3

four-atmosphere, 200 c.c. of each of 1, 2, and 3

high-nitrogen, 25 c.c. of 1 and 3, and 200 c.c. of 2

high-potash and phosphorus, 25 c.c. of 2 and 3, and 200 c.c. of 1

high-potash, phosphorus, and magnesium, 25 c.c. of 2, and 200 c.c. of 1 and 3

high-nitrogen, magnesium, and potash, 25 c.c. of 1, 200 c.c. of 2 and 3, and 166 c.c. of 4

high-nitrogen, magnesium, and phosphorus, 200 c.c. of 2 and 3, and 166 c.c. of 5

high-phosphate, 25 c.c. of 1, 2, and 3, and 166 c.c. of 5.

Seeds were planted on August 10, 1936. On August 20 the seedlings were planted in the cans and watered with the solutions. Solutions were applied daily, and on September 5 it was evident that the plants were becoming uniformly hard. They were then flushed with tap water daily, and on September 20 a solution of $\frac{1}{4}$ -atmosphere concentration was used. No more flushing was necessary, and on October 10 the plants were 22 to 27 inches high and very succulent. The first buds were showing at this time and the original schedule was followed, using $\frac{1}{2}$ atmosphere and the treatments outlined. Nutrient applications were made every second day. The treatments were made in triplicate, and the results appear in table 12.

The production (table 12) was high in every treatment where nitrogen was increased. When all elements were low in concentration except nitrogen, about the same result was obtained as when all were high. High phosphate, potassium, and magnesium did not increase production. Stem length and bud drop were inversely related to production. High potash and phosphate accompanied by low nitrogen increased stem length and bud drop, while high nitrogen had the opposite effect.

On February 17 the plants were showing vegetative symptoms of nutrient excesses. The $\frac{1}{2}$ -atmosphere treatment produced a thick haulm, long internodes, and large leaves. The leaf color was yellow-green. Many buds aborted before the stems (peduncles) were more than $\frac{1}{2}$ inch

TABLE 12. VARYING NUTRIENT RATIOS

Treatment	pH of solution	Average number of stems	Average length of stem (inches)	Average number of stems with no buds	Buds dropped per stem picked (number)
$\frac{1}{2}$ -atmosphere.....	6.6	18.7 $\pm$ 3.49	10.4 $\pm$ 0.57	49.7 $\pm$ 5.96	0.34 $\pm$ 0.08
4-atmosphere.....	5.3	56.0 $\pm$ 6.18	8.4 $\pm$ 0.28	27.7 $\pm$ 1.96	0.23 $\pm$ 0.05
$\frac{1}{2}$ -atmosphere and 4N.....	6.1	55.7 $\pm$ 9.50	8.5 $\pm$ 0.28	24.0 $\pm$ 3.91	0.34 $\pm$ 0.07
$\frac{1}{2}$ -atmosphere and 4 (K and P).....	5.7	11.7 $\pm$ 0.75	10.7 $\pm$ 0.56	54.0 $\pm$ 2.16	0.64 $\pm$ 0.16
$\frac{1}{2}$ -atmosphere and 4 (K, P, and Mg) ..	5.5	17.0 $\pm$ 1.20	10.0 $\pm$ 0.25	50.0 $\pm$ 0.80	0.45 $\pm$ 0.04
$\frac{1}{2}$ -atmosphere and 4 (N, Mg, and K) ..	6.2	65.0 $\pm$ 1.90	9.0 $\pm$ 0.04	23.0 $\pm$ 3.98	0.32 $\pm$ 0.04
$\frac{1}{2}$ -atmosphere and 4 (N, Mg, and P) ..	5.4	69.7 $\pm$ 5.90	8.1 $\pm$ 0.13	23.3 $\pm$ 1.18	0.20 $\pm$ 0.01
$\frac{1}{2}$ -atmosphere and 4P.....	5.6	15.7 $\pm$ 2.2	10.2 $\pm$ 0.42	44.7 $\pm$ 5.80	0.50 $\pm$ 0.04



FIGURE 4. LEAF INJURIES CAUSED BY DEFICIENCY OF POTASSIUM (UPPER ROW) AND EXCESS OF NITROGEN (LOWER ROW)

in length. The 4-atmosphere treatment produced shorter internodes, smaller blue-green leaves, and a thin haulm. High nitrogen produced no terminal response but the older leaves died from the tip to the petiole. The younger leaves became chlorotic when potassium was concentrated in the nutrient solution. When phosphorus alone was concentrated in the nutrient solution, large light-green leaves and long internodes developed. Plants in one of the three cans treated with excess phosphorus showed leaf-fall as obtained in the previous experiment. High potash and phosphate showed the effects of excess potassium more than excess phosphate.

EXCESSES IN SOIL CULTURES

Plants were grown in 6-gallon galvanized cans in composted soil, and were treated with sodium nitrate, muriate of potash, and 16-per-cent superphosphate, to determine the appearance of the injury and to correlate it with the sand-culture results.



FIGURE 5. LEAF DROP CAUSED BY EXCESS PHOSPHATE

Each can contained 54 kilograms of air-dry soil. The first experiment was made to determine the effects upon growth of extreme excesses of the fertilizers which were applied when the plants reached a height of six inches. The treatments were in triplicate, and two applications of each material were made at one-week intervals. Potassium chloride and sodium nitrate were used at the rate of five pounds per 100 square feet of bench area (5 inches of soil), and superphosphate at the rate of 40 pounds per 100 square feet.

Potash and nitrate gave similar results. Both caused yellow-green foliage with green veins near the terminal growing point of the plant after four weeks. Excess potash prevented growth of the terminals. The side branches which started soon became affected in the same way as the terminals. Excess nitrogen caused the lower leaves to become necrotic at the ends, but they remained attached to the plant. Terminal growth was retarded.

Excess phosphate caused the older leaves to become necrotic around the edges and to drop from the plant. The terminal growing points were not affected, and continued to grow as did those of plants given normal concentrations. The symptoms were like those obtained in sand cultures when potash was lacking in the nutrient solution.

VARYING THE RATE OF APPLICATION OF PHOSPHATE AND EFFECTS OF LIME AND POTASH

The symptoms of phosphate excess were so striking that it was thought desirable to determine the smallest amount which would cause injury, and the effects of lime and potash with high phosphate concentration.

Seeds of Majestic Rose sweet peas were planted on May 1, 1936. The cans, holding 54 kilograms of air-dry composted soil, were treated with 16-per-cent superphosphate at the rates of 0, 250, 500, 750, and 1000 grams per can.

Calcium hydroxide was used at the rates of 125, 250, and 375 grams, and muriate of potash at the rates of 25, 75, and 125 grams, per can of soil which had been treated with 1000 grams of phosphate. The fertilizers were thoroughly mixed through the soils, the cans filled, and six seedlings per can planted on May 15. The plants were grown in a cloth house. All treatments were in duplicate. pH determinations made on June 24, 1936, are listed below.

AVERAGE pH DETERMINATION, JUNE 24, 1936

Phosphate, grams per can	pH
1000.....	6.4
750.....	6.5
500.....	6.6
250.....	6.8
1000 plus 375 gms. lime.....	6.6
1000 plus 250 gms. lime.....	6.5
1000 plus 125 gms. lime.....	6.3
1000 plus 125 gms. KCl.....	6.4
1000 plus 75 gms. KCl.....	6.3
1000 plus 25 gms. KCl.....	6.2
No treatment.....	7.4

The differences in pH were so slight that it is doubtful if this had any effect on the growth of plants. The original soil was alkaline and the phosphate tended to make it more acid. The lime and potash had only a slight correcting effect.

The response of the plants was measured by the number of leaflets which fell during definite periods. The data appear in table 13. The data are so variable for the duplicate treatments that individual records are given.

TABLE 13. LEAF DROP PER CAN

Treatment	Period ending—						Total
	Can	June 23	July 1	July 6	July 13	July 20	
No phosphate.....	1 2	0 0	0 0	0 0	0 0	0 0	0 0
250 grams superphosphate.....	1 2	0 0	0 0	0 21	0 8	0 50	0 79
500 grams superphosphate.....	1 2	25 0	82 0	62 65	128 186	54 309	351 560
750 grams superphosphate.....	1 2	9 0	10 4	69 21	335 211	138 192	561 428
1000 grams superphosphate.....	1 2	31 81	58 23	83 127	240 191	80 64	492 486
1000 grams superphosphate and 25 grams Ca(OH) ₂	1 2	0 9	60 91	76 125	244 171	166 64	546 460
1000 grams superphosphate and 250 grams Ca(OH) ₂	1 2	31 0	39 100	82 89	210 238	68 41	430 468
1000 grams superphosphate and 375 grams Ca(OH) ₂	1 2	38 11	130 127	121 129	107 131	64 68	460 466
1500 grams superphosphate and 25 grams KCl.....	1 2	84 45	37 56	58 81	306 200	166 73	651 455
1000 grams superphosphate and 75 grams KCl.....	1 2	26 125	52 89	47 73	112 68	55 55	292 410
1000 grams superphosphate and 125 grams KCl.....	1 2	87 86	52 70	45 56	44 86	31 35	259 333

The data show that 500 grams of superphosphate caused leaf drop; 250 grams caused a small amount of leaf drop in one plot after the same period. The addition of lime and potash increased the injury. Potash at the 12-gram rate was showing injury typical of this fertilizer before the close of the experiment. Heavier applications of potash caused less total leaf drop because of the lack of new leaf formation.

This experiment was repeated in the greenhouse during the winter of 1936 and 1937, using the same kind of soil. The seeds were planted on August 20, and six plants were left to grow in each can. The following treatments were run in triplicate:

1. Soil.
2. Soil and phosphorus, 500 grams per can.
3. Soil and phosphorus as in no. 2, plus CaCl₂ (25 grams per can).
4. Soil plus Na₂SO₄ (25 grams per can).

5. Soil plus phosphoric-acid solution (22.5 c.c. to 3 liters added to the can of soil) added October 19 instead of at the time of planting. The results are given in table 14.

The excess superphosphate and phosphoric acid retarded the growth of the plants and caused leaf injury and drop as previously described. The addition of calcium chloride to a soil which had previously received phosphate had no effect upon growth. Sodium sulfate retarded growth in the early stages, but had no effects after about two months.

TABLE 14. EFFECTS OF PHOSPHATES AND OTHER MATERIALS UPON GROWTH AND LEAF FALL

Treatment	Can number	Plant height (inches)					Height of leaf removal (inches)				
		Oct. 10	Oct. 19	Oct. 29	Nov. 11	Dec. 3	Oct. 10	Oct. 19	Oct. 29	Nov. 11	Dec. 3
Check	1	26	37	42	57	73	0	0	0	0	0
	2	28	38	51	63	82	0	0	0	0	0
	3	32	42	55	70	84	0	0	0	0	0
Phosphate	1	24	36	49	56	74	0	0	0	36	62
	2	18	26	29	35	..	3	10	15	30	..
	3	17	28	36	50	70	3	14	20	65	..
Phosphate and pot-ash	1	23	33	37	49	..*	5	15	24	41	..
	2	15	22	27	33	..	6	20	30	30	..
	3	18	24	27	35	..	6	26	30	33	..
Phosphate and CaCl ₂	1	22	31	40	46	..*	0	15	25	40	..
	2	21	28	35	50	..	10	21	34	40	..
	3	22	31	33	38	..	10	20	25	30	..
Phosphoric acid	1	27	40	50	63	82	0	0	0	40	70
	2	33	41	56	70	75	0	0	0	2	40
	3	35	45	55	66	82	0	0	0	40	82
Sodium sulfate	1	22	28	36	51	66	0	0	0	0	0
	2	12	20	30	40	52	0	0	0	0	0
	3	14	24	27	38	56	0	0	0	0	0

*Removed.

Leaf drop was caused by superphosphate and phosphoric acid but not by sodium sulfate. The addition of calcium chloride and potash to the soil which had been treated with excess phosphate caused greater leaf injury early in the period of growth than did the phosphate alone.

DISCUSSION

All of these experiments were repeated in other years, using similar treatments, and the results have been consistently similar. Sufficient greenhouse space was not available any one year to allow enough replications of the treatments in a commercial way so that statistical methods could be employed in analyzing the data. The consistency of the results, however, is such that they are doubtless significant.

The hardening of plants of sweet peas, accompanied by dark green leaves, as so commonly occurs in commercial greenhouses, has been thought to be due to a deficiency of nitrogen for growth of the plants. This hardening has been produced in soils high in nitrate. It has also been produced in sand cultures treated with solutions high in nitrate, high in total salts, or low in phosphate. It has been impossible to pro-

duce this type of hardened growth when the soil was extremely low in nitrate or when no nitrate was present in the nutrient solution supplied to plants growing in sand.

The plants obtained sufficient nitrogen for growth probably through the nodule-forming organisms, when the culture medium was low in it during the entire period of growth. The leaves of the plants showed a deficiency of nitrogen for chlorophyll formation during the early stages of growth when no nitrogen was present in the medium. The green color later became intensified, even though no nitrogen was supplied to the soil.

Some tests were made with inoculation treatments of the seed, but it appeared to have no effect. All plants became inoculated by natural contamination in a short time under greenhouse conditions if the nitrogen level of the soil was low. Previous work reviewed by Fred, Baldwin, and McCoy (1932) shows that low nitrate content of the culture medium stimulates nodulation, and high nitrate retards it. Doubtless nitrogen did not become deficient for growth although it was absent in the medium, because it was supplied to the plants in sufficient amounts through the nodules on the roots.

Plants supplied with nitrogen during the early period of growth showed nitrogen deficiency in the foliage when the nitrogen was removed from the solution in the later stages of growth. This treatment caused the vines to stop growth and become woody. It was always accompanied by a yellowing of the foliage and should never be confused with the dark-green foliage which accompanies hardening when the culture medium is low in phosphate or high in nitrate or total salts. These plants probably suffered for lack of nitrogen because the nodules were not developed sufficiently to supply the nitrogen required.

Shortening of the flower stems was found to accompany hardening of the plants. Shortest stems were produced when the nitrate content of the culture medium was the greatest. Stem length decreased rapidly in spring when no nitrogen was present in the medium. This shortening of stems was accompanied by light-green leaves, and was overcome by the addition of nitrogen. The longest stems always occurred when the nitrate content of the medium was intermediate to low. It is doubtful if nitrogen fertilizer as used by commercial growers during the later stages of growth ever lengthens the stems if the plants are well nodulated. The evidence, in light of knowledge of the fertilizer treatments, is that the stems become shorter and the plants harden more than ever when the additional fertilizer is added. This is especially true if the plants are hardened to the extent that they are dark green.

Bud drop was greatest when the stems were longest and when the vines were most succulent. It was most prevalent when the nitrate content of the medium was intermediate. High concentrations of nitrate or no nitrate reduced bud drop. Bud drop is certainly not associated with high fertilizer concentration.

Farnham (1935) found that high total concentrations of the nutrient solution resulted in less bud drop, more production, and shorter stems than did lower concentrations. This agrees with the results of these experiments. However, it is evident from the data presented that nitrogen is the element most important in the nutrient solution. High con-

centrations of phosphorus and potash did not have the same effects as did high concentrations of nitrogen.

Commercial sweet-pea growers usually increase bud drop when they supply the soil with great amounts of water during periods of low light intensity.

Unpublished data of the author's indicate that temperatures above 50° F. do not produce as much bud drop as do temperatures below 50°.

The addition of chopped straw or of sugar to soils high in nitrate reduced the nitrate concentration and increased stem length and production, as well as increased the bud drop. The straw also increased the porosity of the soil, and doubtless increased soil aeration. Sugar had the opposite effects so far as was visible. Both had a similar effect on growth of plants and on nitrate concentration of the soil.

Superphosphate has been recommended to harden plants and prevent bud drop. These experiments show that it does the exact opposite of this, and, if supplied in sufficient amounts, will cause the older leaves to become necrotic around the edges and to drop from the plant. The terminal part of the plant is unaffected and continues growth. The injury has been observed in greenhouses on Long Island, but has never been serious.

It is impossible to determine the difference between this injury and that caused by lack of potash, by studying leaf symptoms. The leaf drop does not result from other fertilizer injuries. Applications of potash to phosphate-injured plants did not correct the growth. Lime in the form of calcium chloride and calcium hydroxide increased the injury produced by phosphate. Sodium sulfate was added in one treatment to determine if the injury might be due to sulfate. The leaf fall was doubtless due to the phosphate because it occurred when phosphoric acid was added to the soil.

Potash deficiency did not cause more bud drop than did the usual concentration of potash. The necrotic leaf margin and leaf drop were characteristic of potash deficiency. An excessive amount of potash caused a reduction in bud drop and hardened the vines, when all other elements were low in concentration. This was not noticeable when other elements were in greater concentration.

CONCLUSIONS

1. Hardening of sweet peas was caused when the soil was high in nitrate concentration or when the plants were grown in sand and supplied with a nutrient solution deficient in phosphate.

2. The nitrate content of the soil was reduced by the incorporation of chopped straw before planting. This prevented hardening of the plants in soil high in nitrate.

3. Soils and nutrient solutions low in nitrate caused plants to produce succulent growth, and increased bud drop.

4. Bud drop was reduced when the soil or nutrient solution was high in nitrate.

5. Hardening of plants was accompanied by short stems and reduced bud drop. Production often increased.

6. Plants which had nodules obtained enough nitrogen for growth in

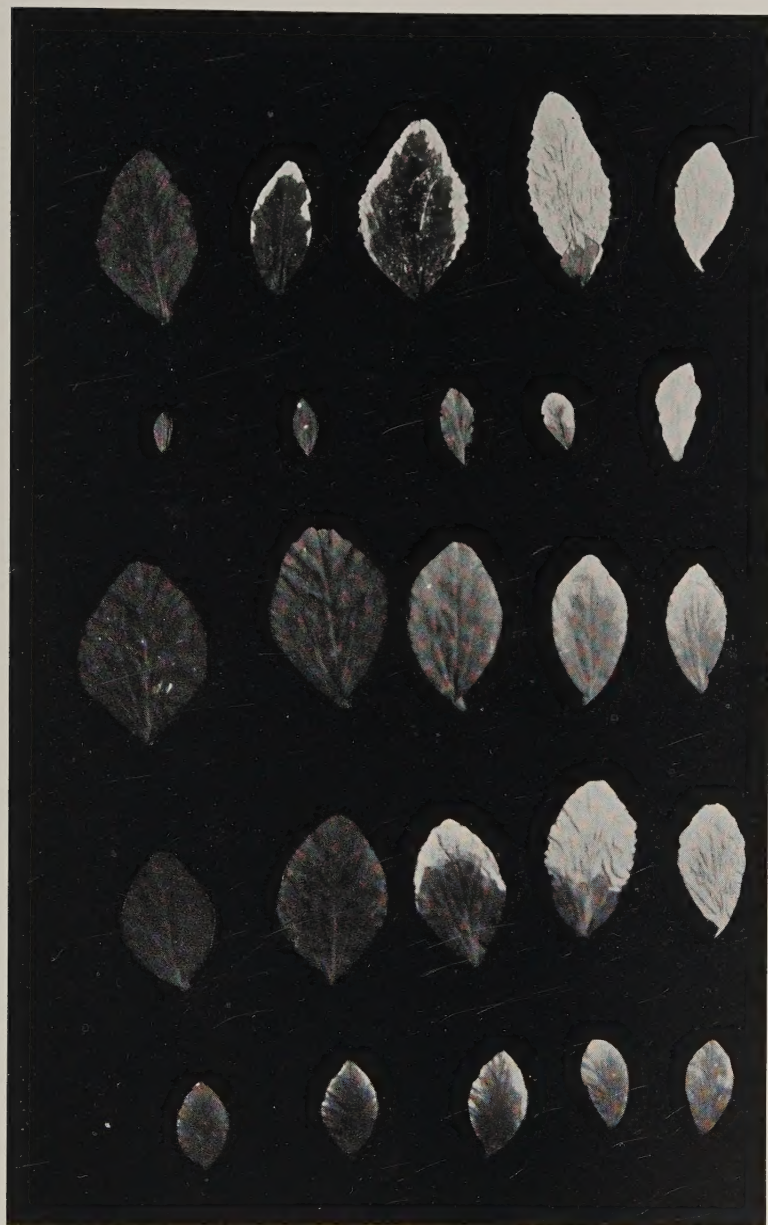


FIGURE 6. LEAF SYMPTOMS OF NUTRIENT DEFICIENCIES AND EXCESSES

Top to bottom:

Minus potash

Minus phosphate

Minus nitrogen in late stages of growth

Excess nitrogen

Minus nitrogen during entire growing period

soils very low in nitrate and in sand cultures not supplied with nitrogen. Such plants did become hardened during the early stages of growth, but this was accompanied by chlorotic foliage.

7. Nitrogen deficiency appeared as a yellowing of the foliage of the plants. The leaves remained on the plants. The older leaves were affected first.

8. Potash deficiency and phosphate excess caused a marginal leaf injury followed by leaf fall. The older leaves were affected first. The terminal part of the plant continued a succulent-growth extension.

9. Phosphate deficiency caused the development of blue-green, small leaves. The internodal spaces were short and the tendrils were purple.

10. High nitrogen and high total salts in the seedling stage caused blue-green, small leaves to form; the internodes were short, and the roots injured.

11. High nitrogen during the later stages of growth caused the older leaves to die from the margin inward. They did not readily fall from the plant.

12. High potash caused yellowing of the terminal growth, and root injury.

13. Most hardening is due to an excess of nitrogen or of total soluble salts in the soil.

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